Time invariance violation is a physical base of atomic Bloch oscillations in an optical lattice

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Abstract

The physical mechanism of phenomenon is explained as a result of inequality of forward and reversed processes in optics. The importance of experimental study of its invariance relation is discussed.

PACS number: 03.75.-b, 32.80.-t

There is rather usual situation in nonlinear optics when a phenomenon has mathematical description, but clear explanation of its physical mechanism is absent. Clear physical sense appears if we use the concept of inequality of forward and reversed processes in optics. Such approach has quite reliable basis [1].

In this note we shall discuss the situation with explanation of the Bloch oscillation of ultracold atoms in a vertical optical lattice, formed by two counterpropagating beams [2 - 4]. Under action of gravity the atoms perform a cyclic motion in the vertical direction. The measurement of oscillating frequency allows a sensitive determination of the acceleration of gravity or forces at the micrometer length scale.

According to the existing theoretical concept the physical base of the Bloch oscillations is the polarization interaction of the atoms with the standing optical wave. The corresponding theoretical description is very complex and non-intuitive [5, 6]. It gives for the Bloch oscillations frequency following expression:

$$\nu_B = \frac{mg\lambda}{2h} \tag{1}$$

where m is the atomic mass, g is the acceleration of gravity, λ is the wavelength of the light, and h is Planck constant [2].

Below we shall deduce the formula (1) by very simple and quite intuitive way. We also shall give the alternative physical explanation of origin of the phenomenon.

When the magneto-optical trap is switched off, the ultracold atoms start to fall down under action of the gravity (Fig.1). At the certain moment of time the Raman optical transition takes place and the atoms receive a double recoil moment in the opposite direction. The obtained recoil energy ($2E_R$) allows for atoms to return in the initial point. The amplitude (height) of atomic

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oscillations (H) may be deduced from condition $E_R = h^2/2m\lambda^2 = mgH$ and it is given by

$$H = \frac{h^2}{2m^2\lambda^2 g} \tag{2}$$

For ^{88}Sr and $\lambda = 532$ nm this height equals $3,66\mu m$ or $6,88\lambda$ [2]. For ^{40}K and $\lambda = 873nm$ it equals $6,57\mu m$ or $7,5\lambda$ [3,4]. But for ^{6}Li atoms this value should reach $292\mu m$ or $334,5\lambda$ (for $\lambda = 873nm$).

The fall time (t) of atoms is related to the height by $H = gt^2/2$. So, for the period of oscillations (T) we obtain:

$$T = 2t = \frac{2h}{mg\lambda} = \frac{1}{\nu_B} \tag{3}$$

The equations (1) and (3) are identical.

For the explanation of physical origin of atom oscillations we should answer for two questions:

1) Why does the Raman transition occur only at the certain moment of time?

2) Why is the Raman recoil momentum directed only in one side?

The answer on these questions is that we deal with a direct manifestation of a time reversal noninvariance or inequality of forward and reversed processes in optics. This situation is completely the same as in the case of splitting and mixing of a photons [7, 8]. Those experimental results clearly show that the reversed optical process is much more efficient, than the forward one. In our case the Raman transition, which return the atom into the initial point is the reversed transition. In contrast, the transition, which recoil pushes the atom down, is the forward Raman transition. The experimental results show, that the cross-section of reversed transition exceeds in many orders of magnitude the cross-section of forward transition.

Because of a recoil energy of Raman transition is fixed, the moment of time for the reversed transition in the discussed case should be also fixed.

It is clear, that the important task now should be an experimental evaluation and measurement of a ratio of cross-sections for forward and reversed transitions. Different methods may be used for this goal. The most simple and natural way is the using of pump-probe method with weak, collinear, copropagating probe laser pulse. The idea of such experiments was discussed early [9 - 11]. It is surprising that the results of such simple experiments are absent in literature till now.

In conclusion, we propose the alternative physical explanation of origin of atomic Bloch oscillations in an vertical optical lattice. This explanation is based on the concept of inequality of forward and reversed processes in optics. The importance of experimental study of the invariance relation of forward and reversed transitions is discussed once again.

References

[1] V.A.Kuz'menko, E-print, physics/0506023

[2] G.Ferrari, N.Poli, F.Sorrentino, and G.M.Tino, Phys.Rev.Lett. **97**, 060402 (2006).

[3] I.Carusotto, L.Pitaevskii, S.Stringari, G.Modugno, and M.Inguscio, E-print, cond-mat/0503141.

[4] E.Roati, E. de Mirandes, F.Ferlaino, H.Ott, G.Modugno, and M.Inguscio, Phys.Rev.Lett. **92**, 230402 (2004).

[5] T.Hartmann, F.Keck, H.J.Korsch and S.Mossmann, New J.Phys. **6**, 2 (2004).

[6] O.Morsch and M.Oberthaler, Rev.Mod.Phys. **78**, 179 (2006).

[7] B.Dayan, A.Pe'er, A.A.Friesem and Y.Silberberg, E-print, quant-ph/0302038

[8] B.Dayan, A.Pe'er, A.A.Friesem and Y.Silberberg, Phys.Rev.Lett. **93**, 023005 (2004).

[9] V.A.Kuz'menko, E-print, physics/0406064.

[10] V.A.Kuz'menko, E-print, physics/0603200.

[11] V.A.Kuz'menko, E-print, physics/0608038.

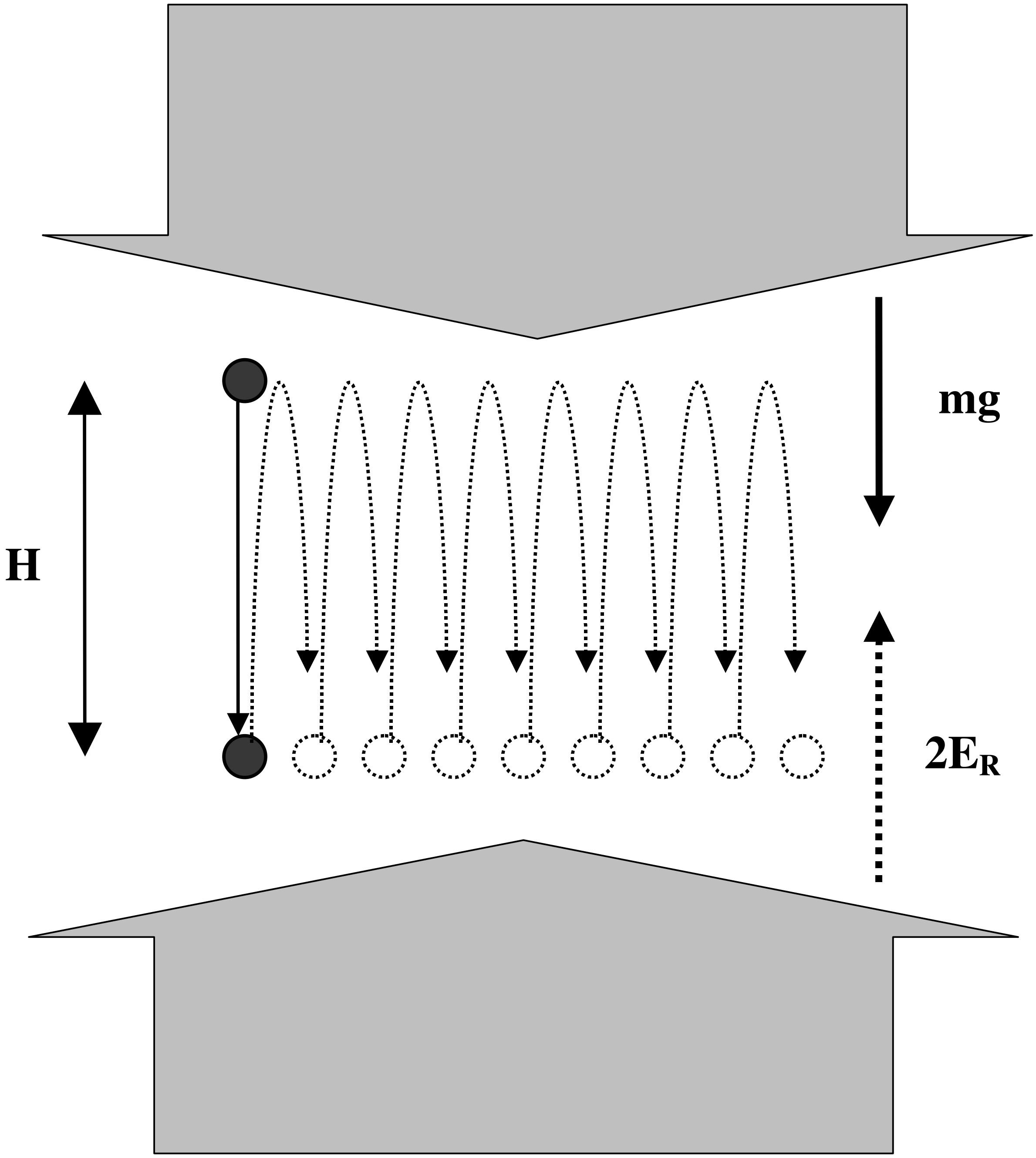

Fig.1 Sketch of the explanation of physical origin of atomic Bloch oscillations in a vertical optical lattice.